Numerical Aspects of NASA Trap-Wing Computations using the DLR TAU Code

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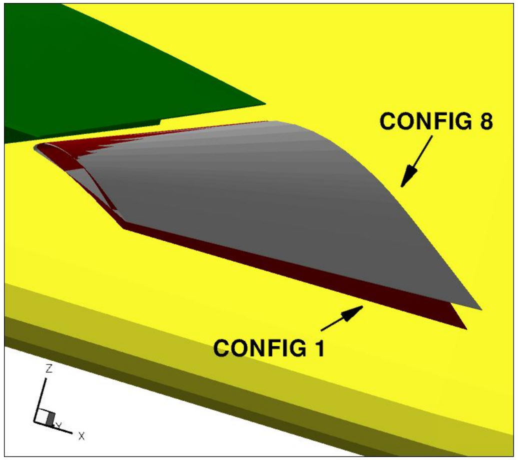
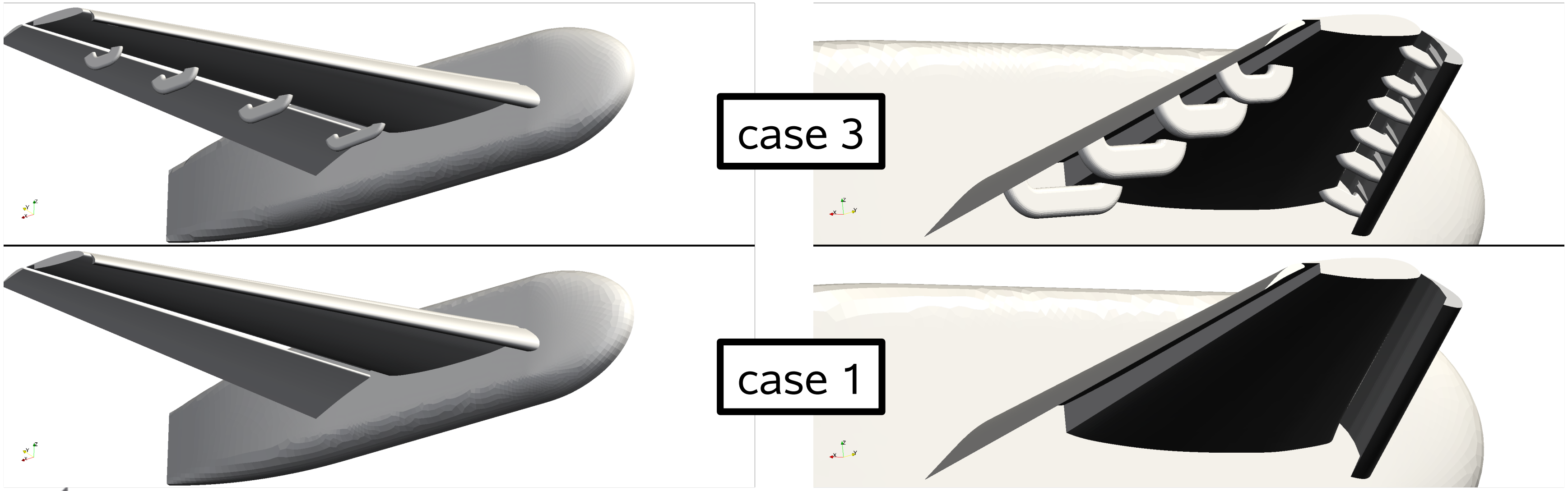
First AIAA High Lift Prediction Workshop (HiLiftPW) Introduction

- Workshop on June 25-26 2010
- DLR objectives
  - Assess the capabilities of SolarTAU for swept, medium/high-aspect ratio wings at high-lift conditions
  - Observe “state-of-the-art” of the CFD community (28 participants)
  - Identify areas needing additional research and development
- Focus
  - NASA “Trap Wing”; three-element section
  - Perform grid convergence study to separate discretization from modeling errors
  - Perform computations on slightly different configurations (flap deflection angle) to compare differentials (Δ_{CFD} vs. Δ_{exp})

Cases

- 2 flap settings, nominal deflection of 30° (case 1; config 1) and decreased deflection of 25° (case 2, config 8)
- Optional case with slat/flap brackets as tested in the wind tunnel (case 3)





Grid Generation

- For case 1, family of quad/hexa-dominant, unstructured grids generated with Solar featuring consistent scaling (volume grid scaling factor = 3)
  - Same procedure as developed for DPW4 (AIAA-2010-4672)
    - Source sizes scaled by a factor of $\sqrt[3]{3}$ (≈ 1.4422), affecting both surface and volume meshing
    - Influence radii (r1 & r2) not changed, being coupled to geometry
    - Consistent scaling of expansion ratio, to keep the total near-field layer extent similar between grid levels
  - Proven grid family generation process
- Two additional grids for case 2 and case 3

Grid Generation

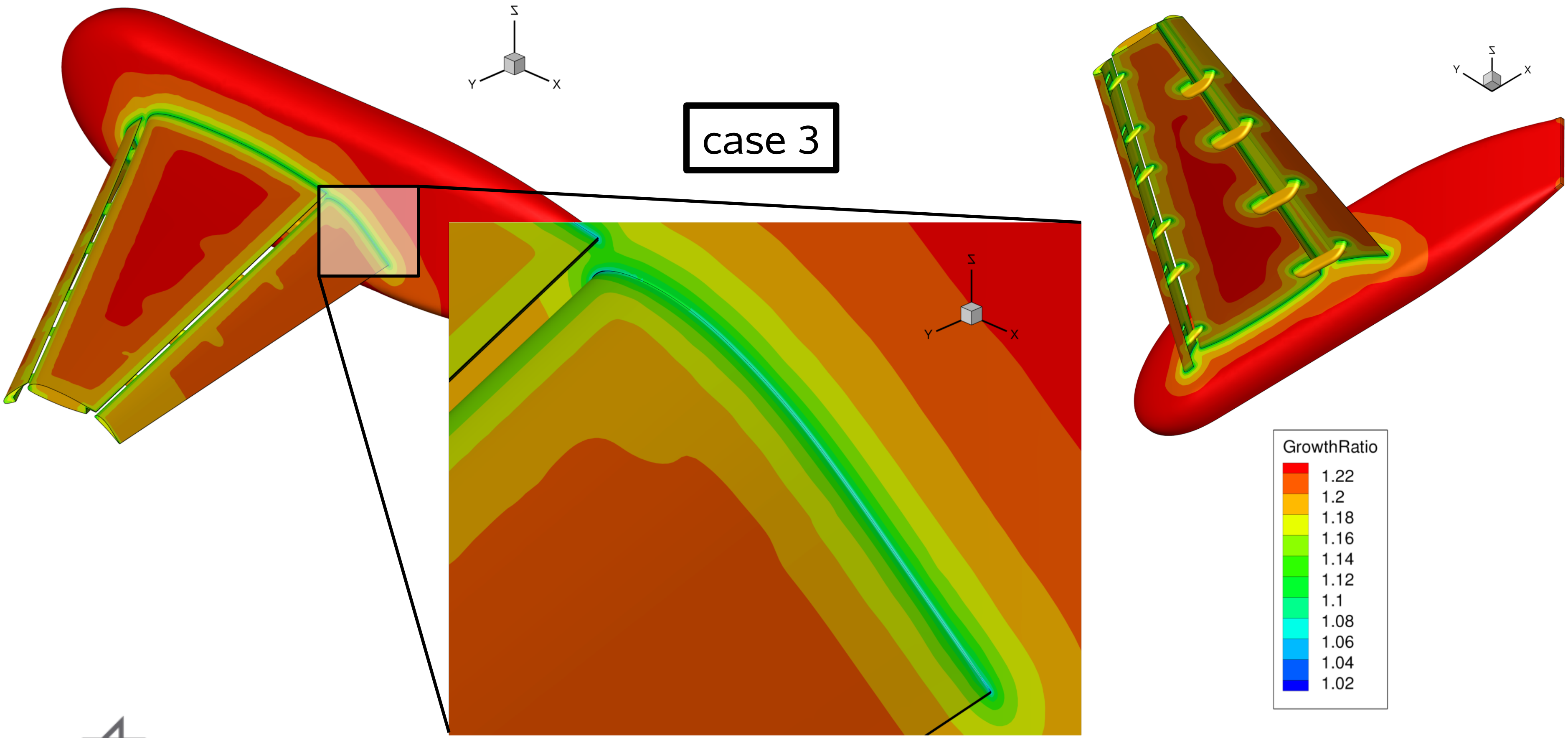
- Gridding guidelines set no hard constrains on amount of points for grid convergence study
  - Self-imposed DLR target of approx. 10, 30, 90 mio. points; final grids slightly bigger
- All feasible points of gridding guidelines are fulfilled by Solar grids
  - Not fulfilled: e)2-3) variable growth rate to capture wakes

Final grid properties

grid	total points [$\times 10^6$]	wall-normal layers	exp. Ratio; target (real)	first layer spacing [inch]
coarse	12,31	35	1.25 (1.0123 – 1.372)	6.0×10^{-5}
medium	36,97	51	1.166 (1.0009 – 1.238)	4.16017×10^{-5}
fine	110,75	74	1.112 (1.002 – 1.159)	2.8845×10^{-5}
config 8	37,06	51	1.166 (1.0009 – 1.238)	4.16017×10^{-5}
brackets	39,71	51	1.166 (1.0011 – 1.238)	4.16017×10^{-5}

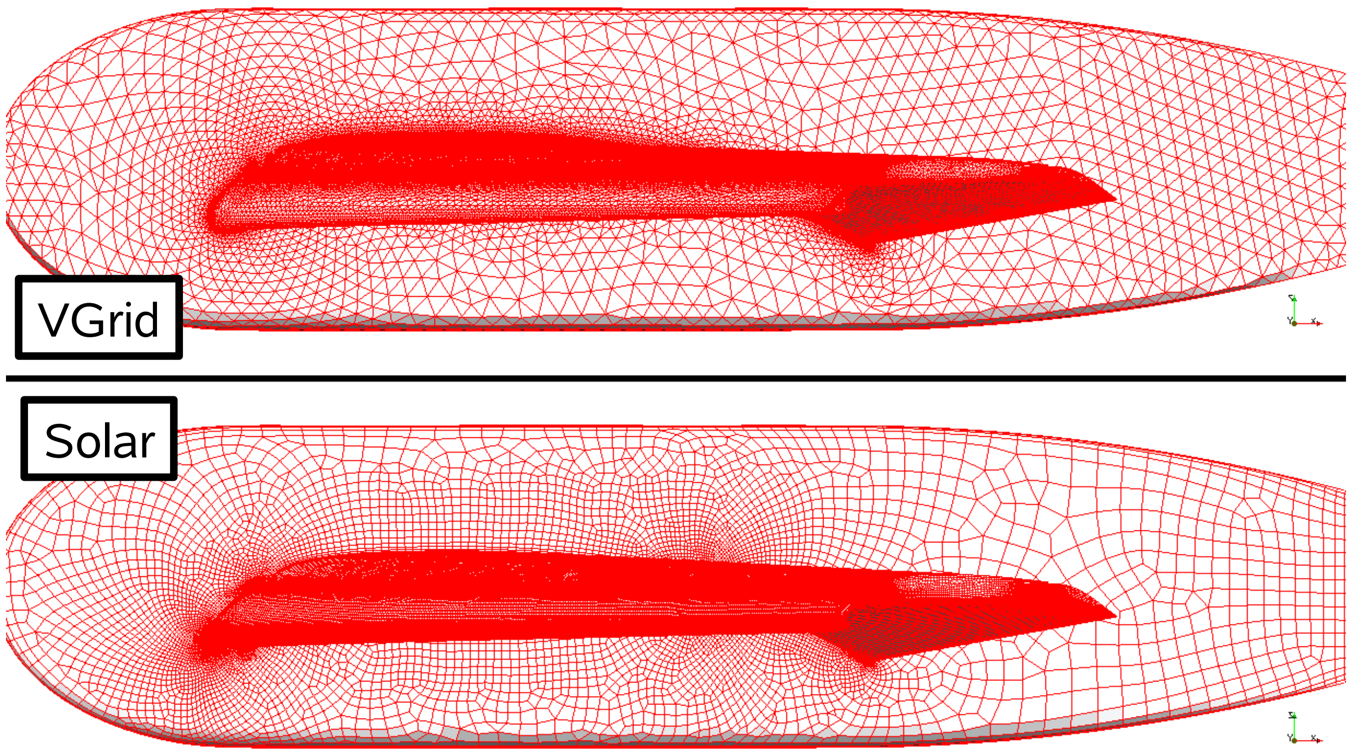
Grid Generation

- Variable expansion ratio decreases from target value near concave surface intersections (wing/body junction)

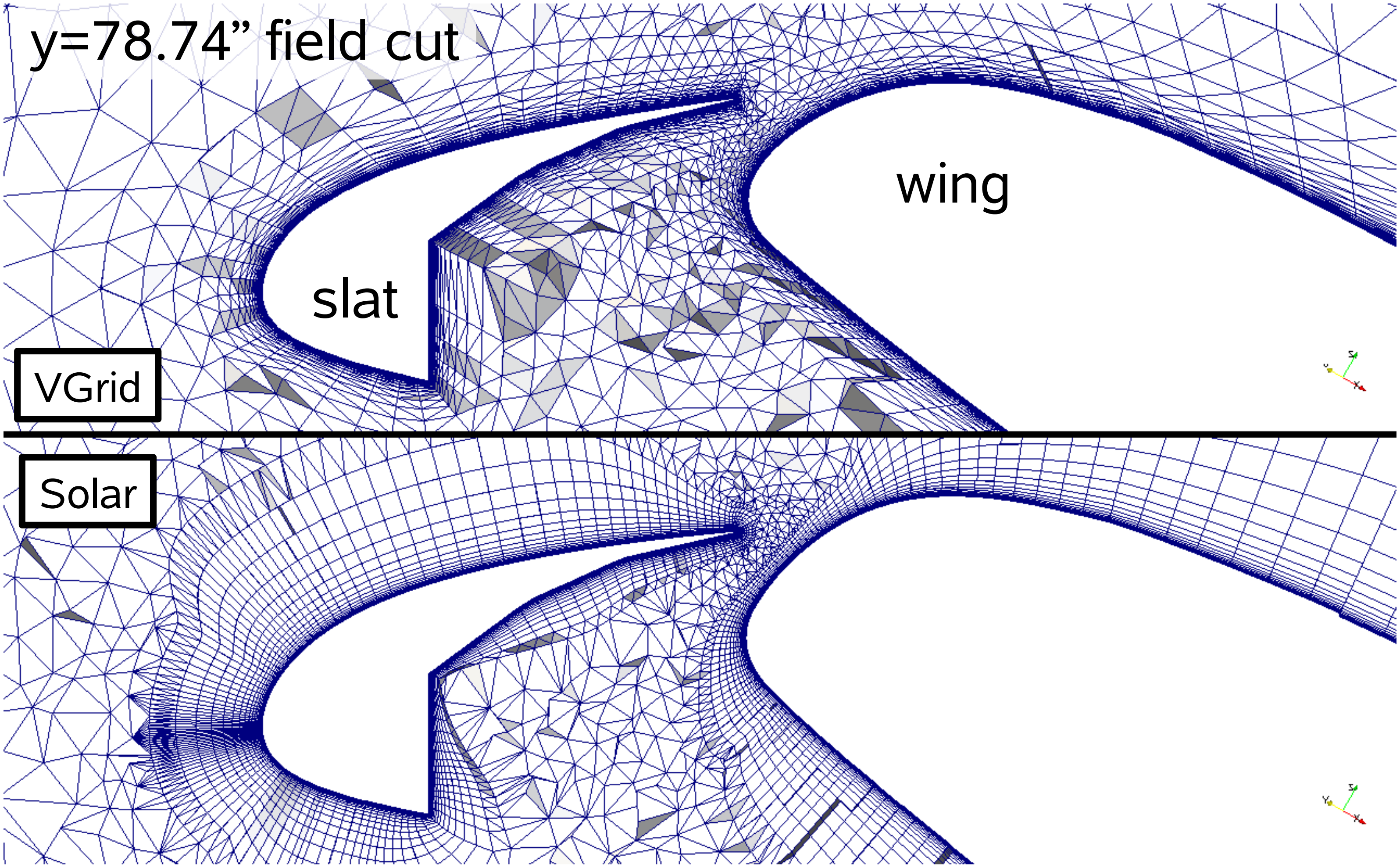


Comparisons VGrid vs. Solar

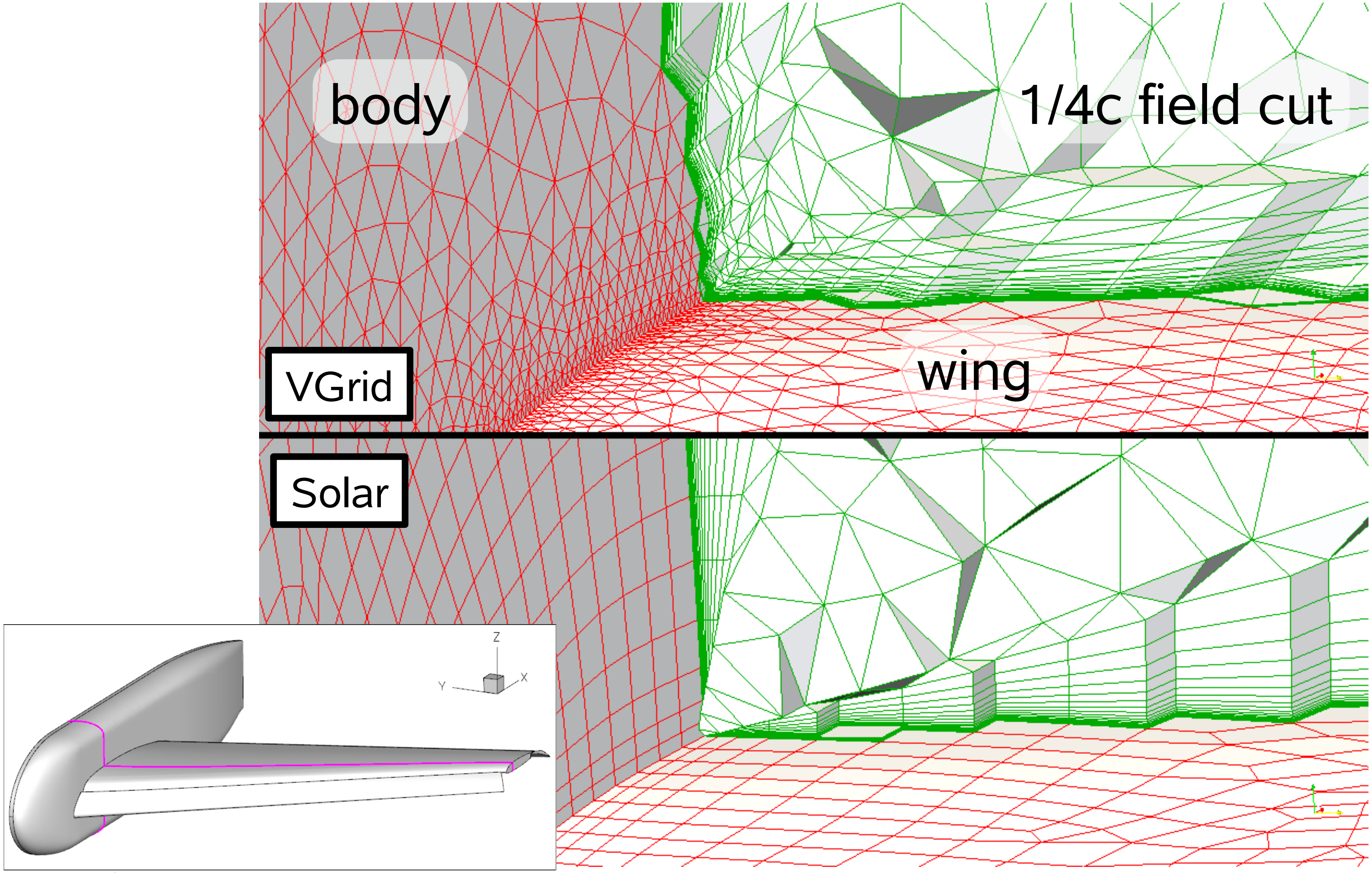
- Comparison between Solar and full-tetra VGrid (Unst-Tet-Nodecentered-A-v1)



Comparisons VGrid vs. Solar



Comparisons VGrid vs. Solar

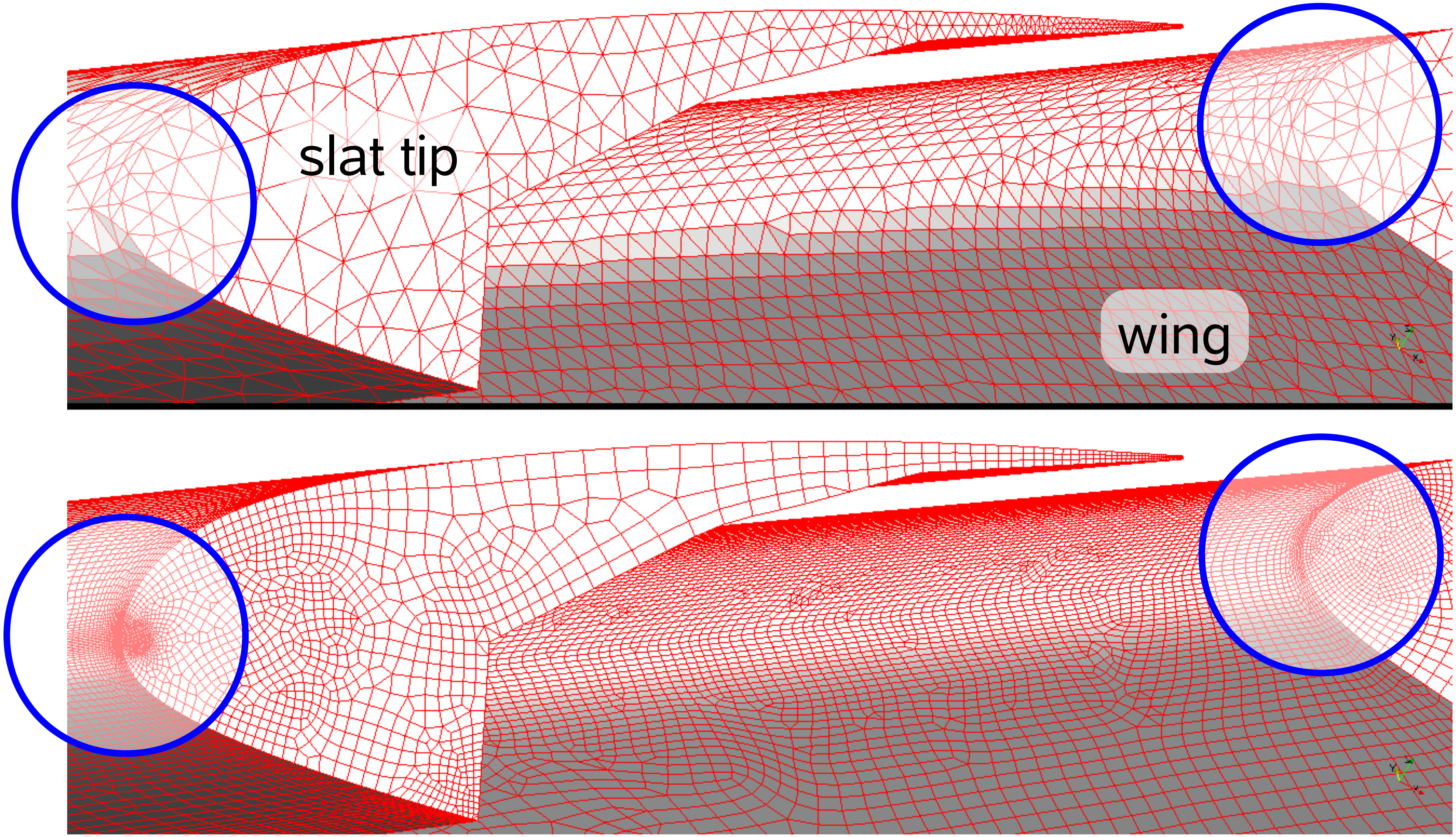


Comparisons VGrid vs. Solar

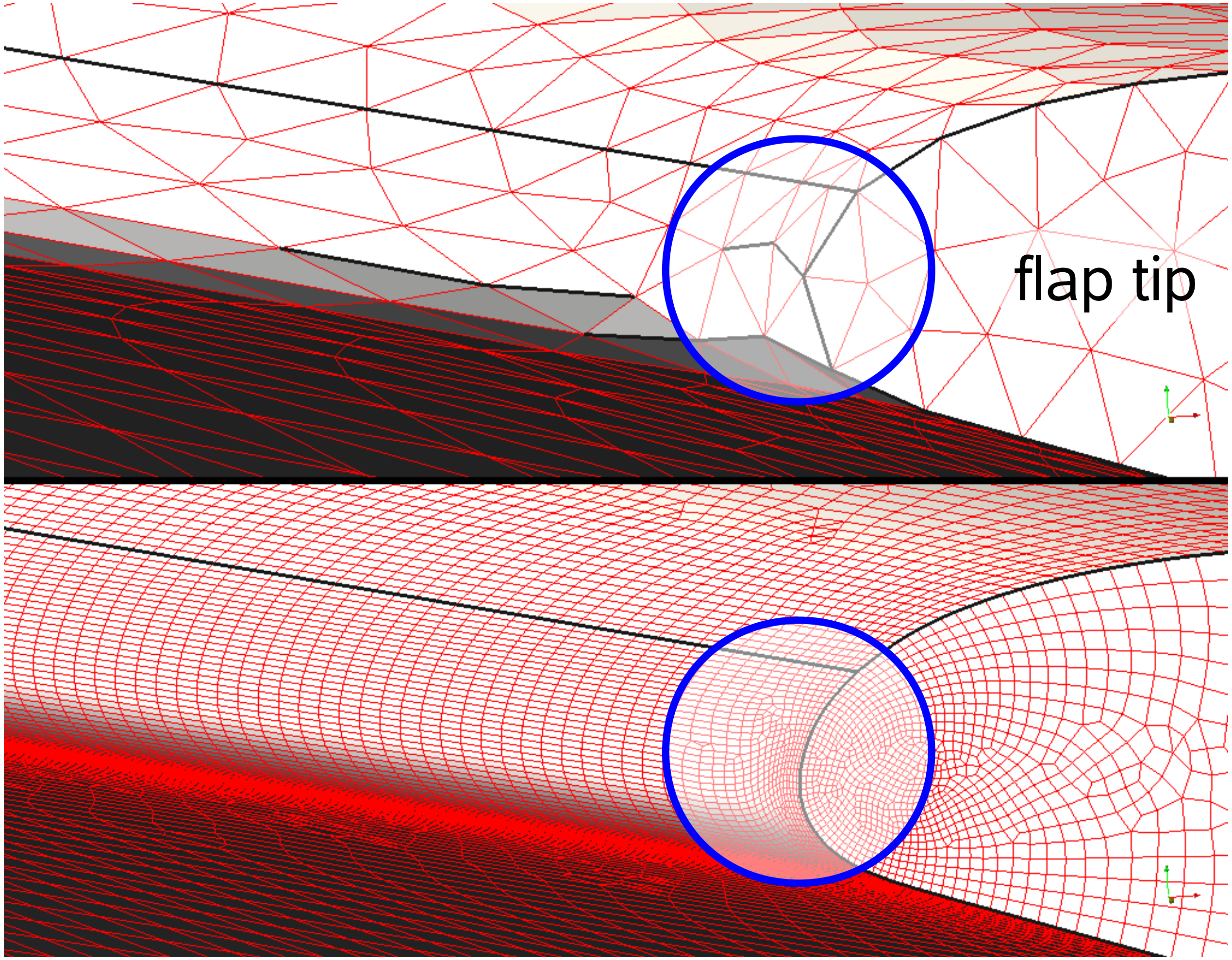
- VGrid family ...
  - … quite similar to Centaur grids
  - ... features smoother interface between near-field and tetra region both in the critical wing-body junctions and in the slat/wing coves
  - ... ends up at 3.65/10.96/32.3 mio. points

    (how can this be achieved?)
  - ... does not comply to gridding guidelines in some points, for example
    - Span-wise discretization at tips; factor 15, 3, 10 (slat, main, flap) coarser
    - Chord-wise leading edge discretization; factor 15, 3, 10 (slat, main, flap) coarser

Comparisons VGrid vs. Solar

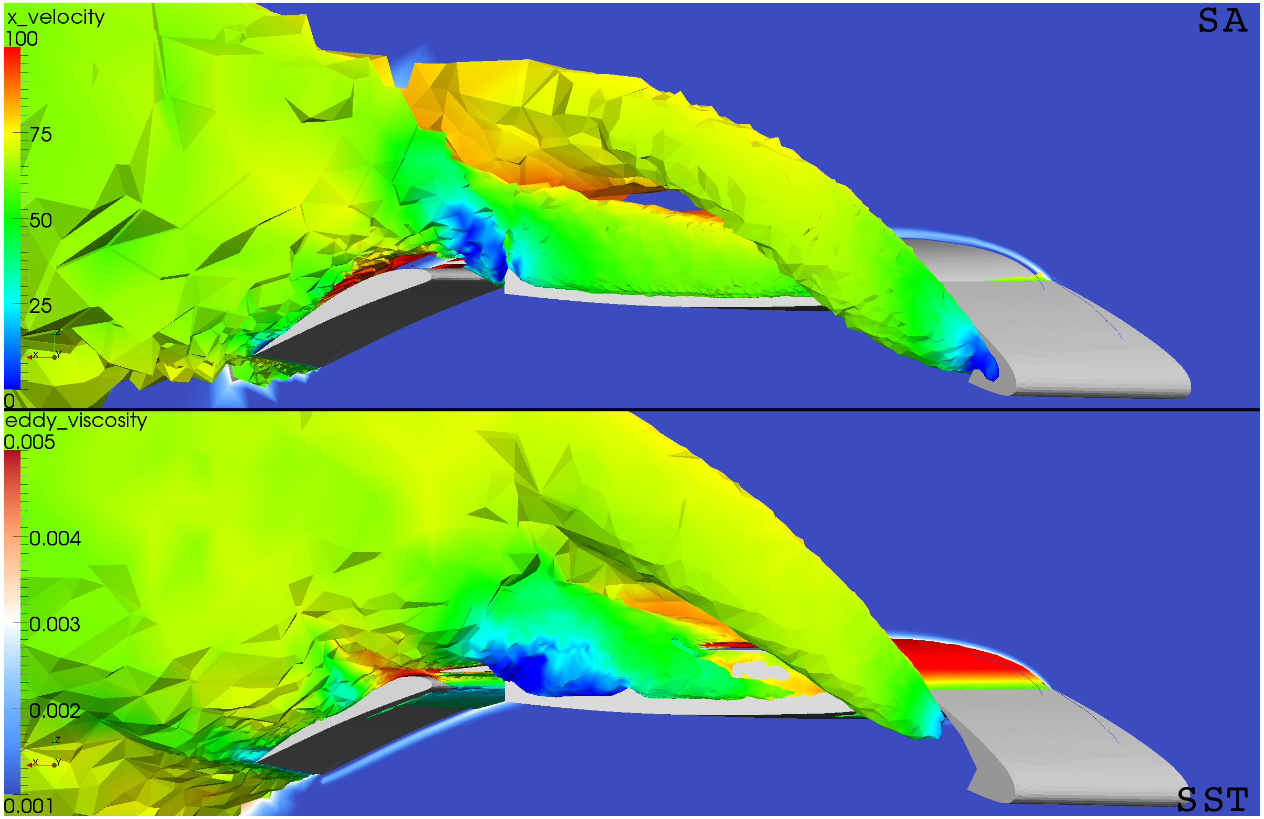


Comparisons VGrid vs. Solar



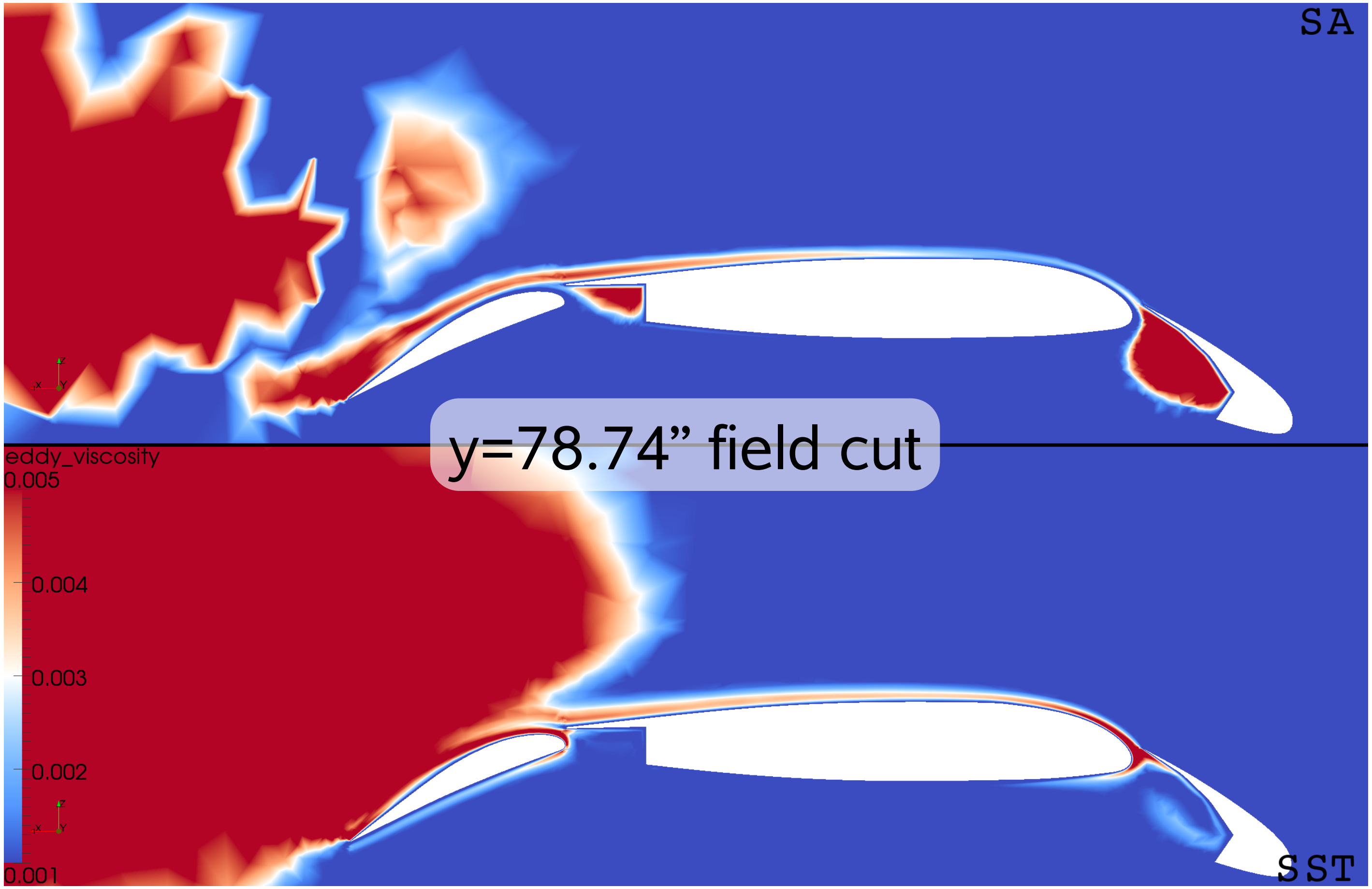
Initial VGrid Results

- Early access to VGrid grids was useful to analyze the configuration



Tip vortex system analyzed with SA and SST

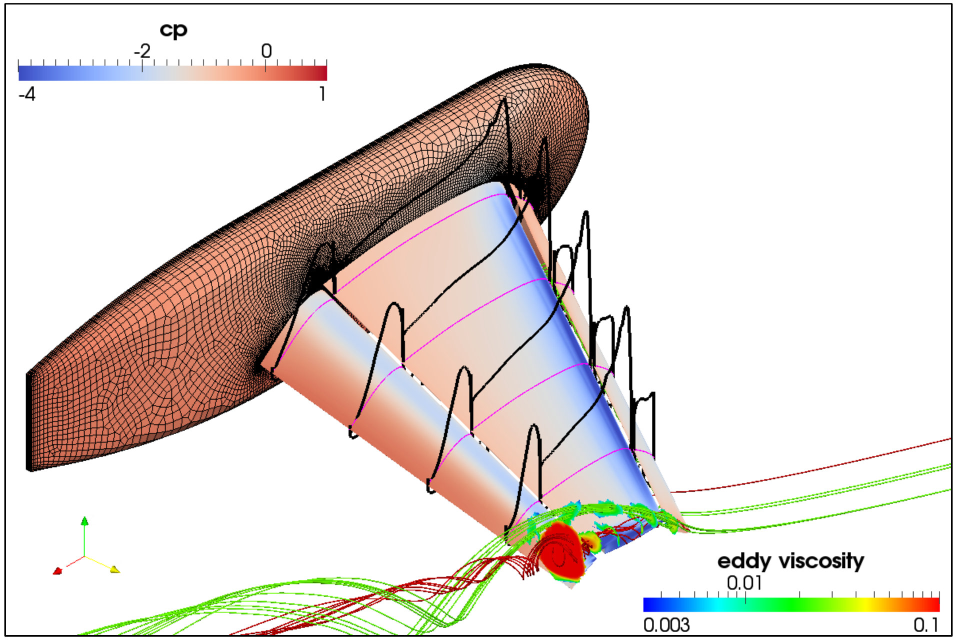
Initial VGrid Results

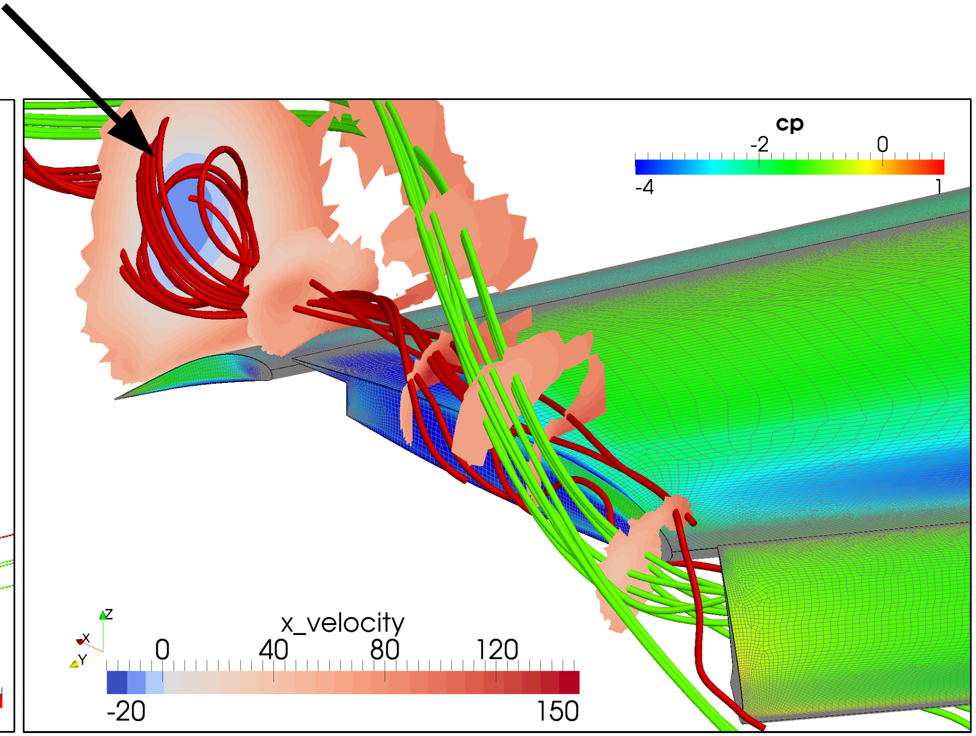


Large difference of eddy viscosity between SA and SST in slat and wing coves; remains to be confirmed on Solar grids

Initial Solar Results

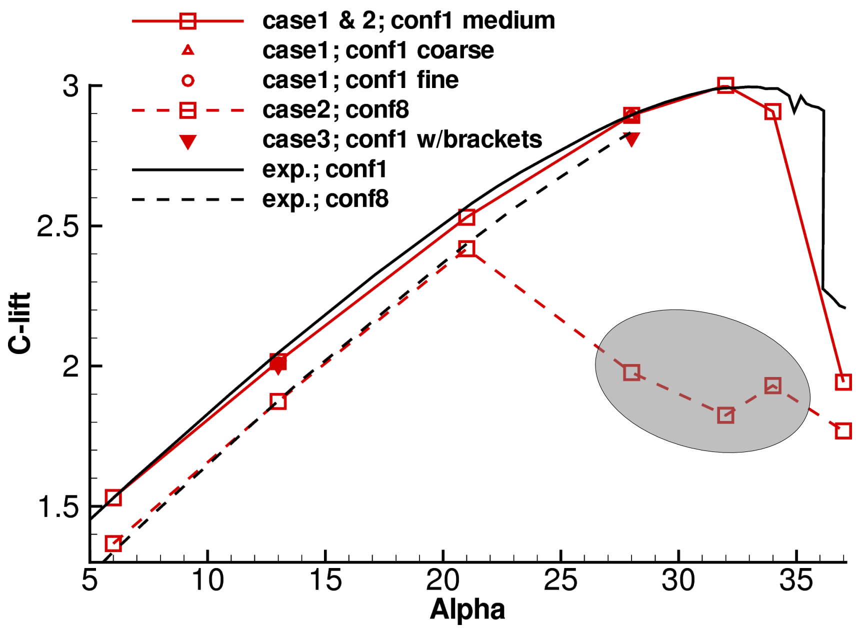
- Preliminary results show a strong slat-tip/main-tip vortex interaction already at moderate angles of attack (13°)
- Main element tip vortex bursts over the flap-tip; volume discretization is conjectured to be insufficient for capturing this phenomenon

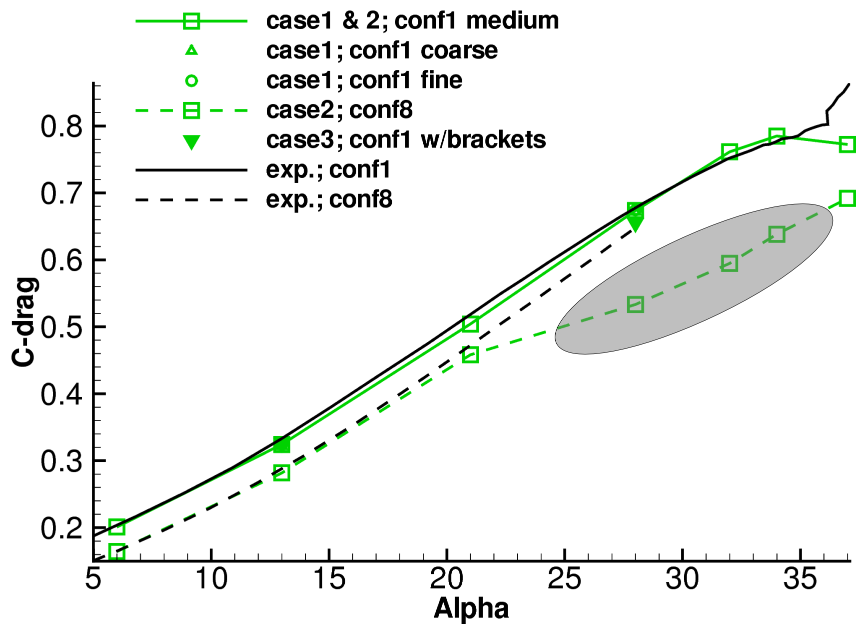




Lift/Drag vs. Alpha

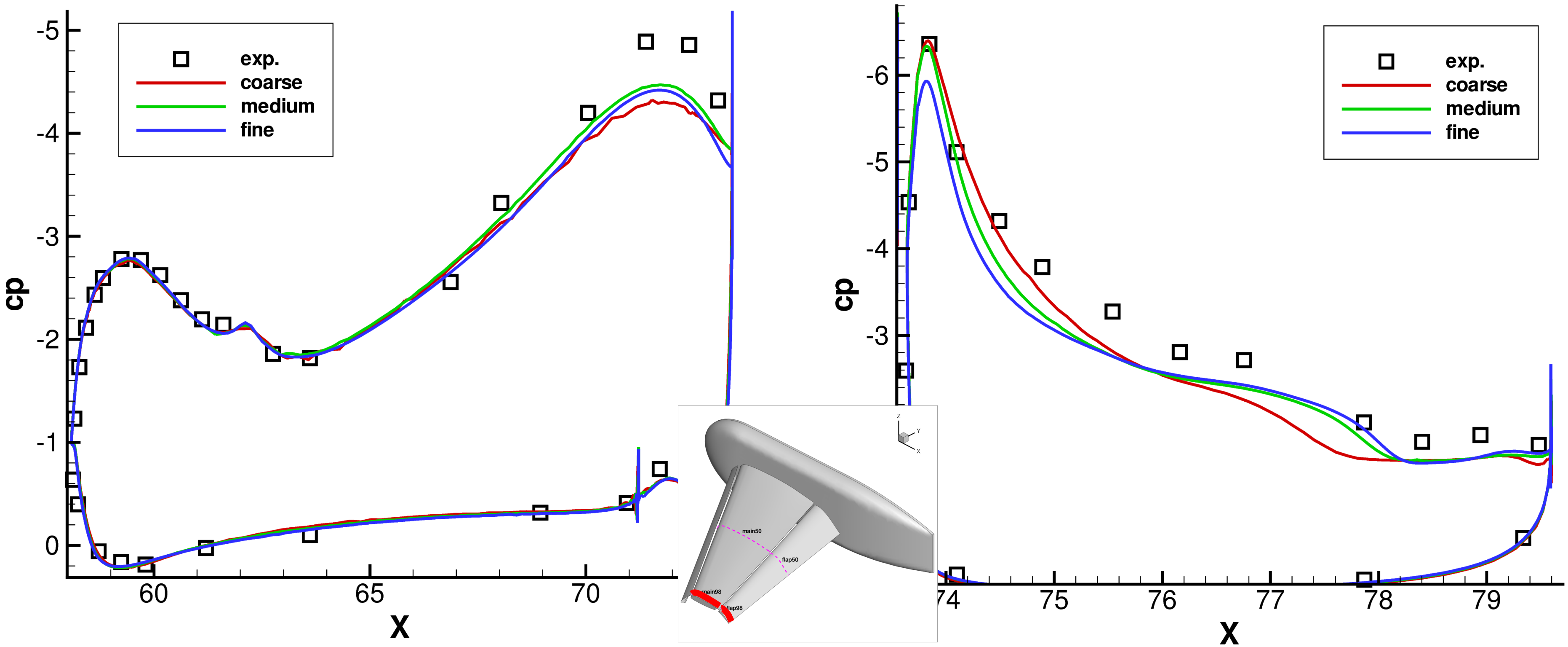
- The overall aerodynamic behavior is acceptable in terms of
  - C_L&C_D vs. aoa (note that results for case2 after 21° are not converged)
  - effect of decreased flap deflection angle (up to aoa=21°)
  - expected brackets influence; little effect at 13°, lift penalty at 28°





Grid Convergence

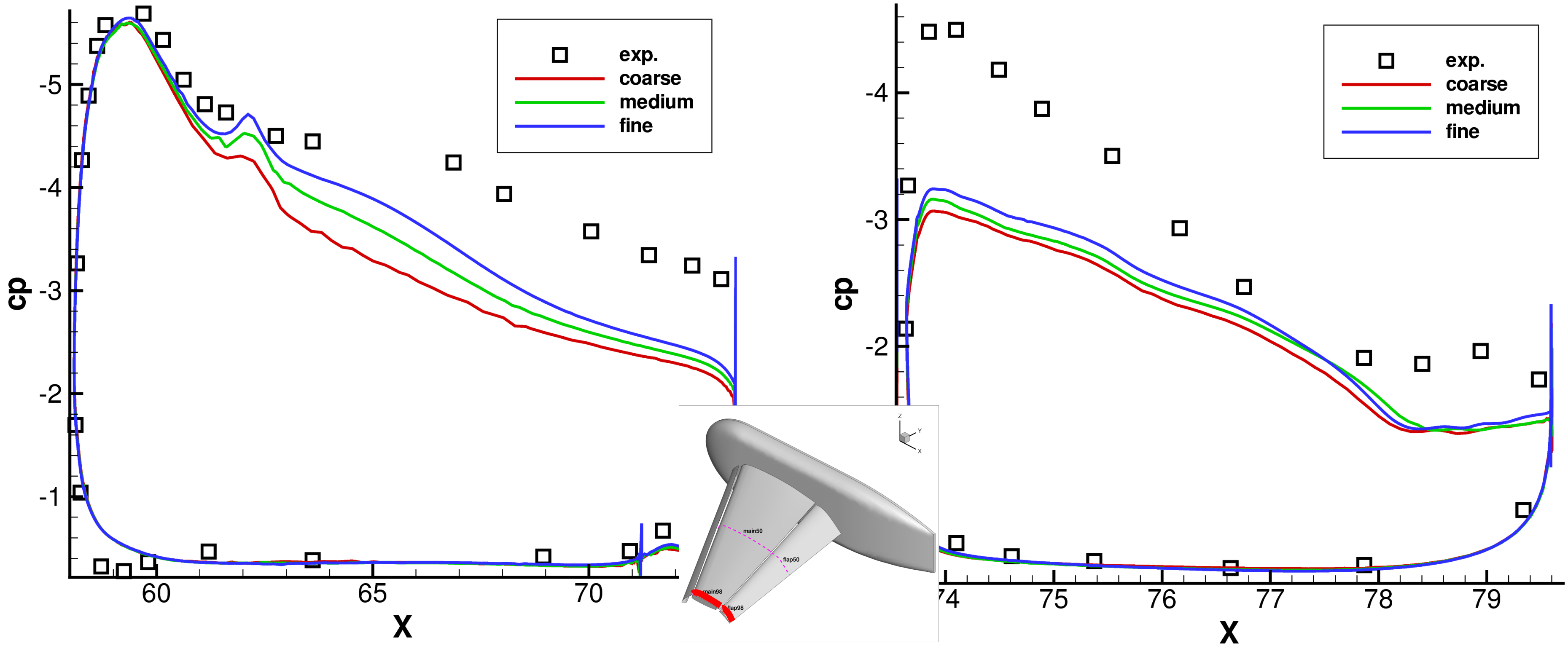
- For aoa=13°, grid convergence over span, but no grid convergence in tip region, which should be due to under-resolved tip vortex system



case 1; aoa=13°; pressure coefficient on main element (left) and flap (right) at y/2b=98%

Grid Convergence

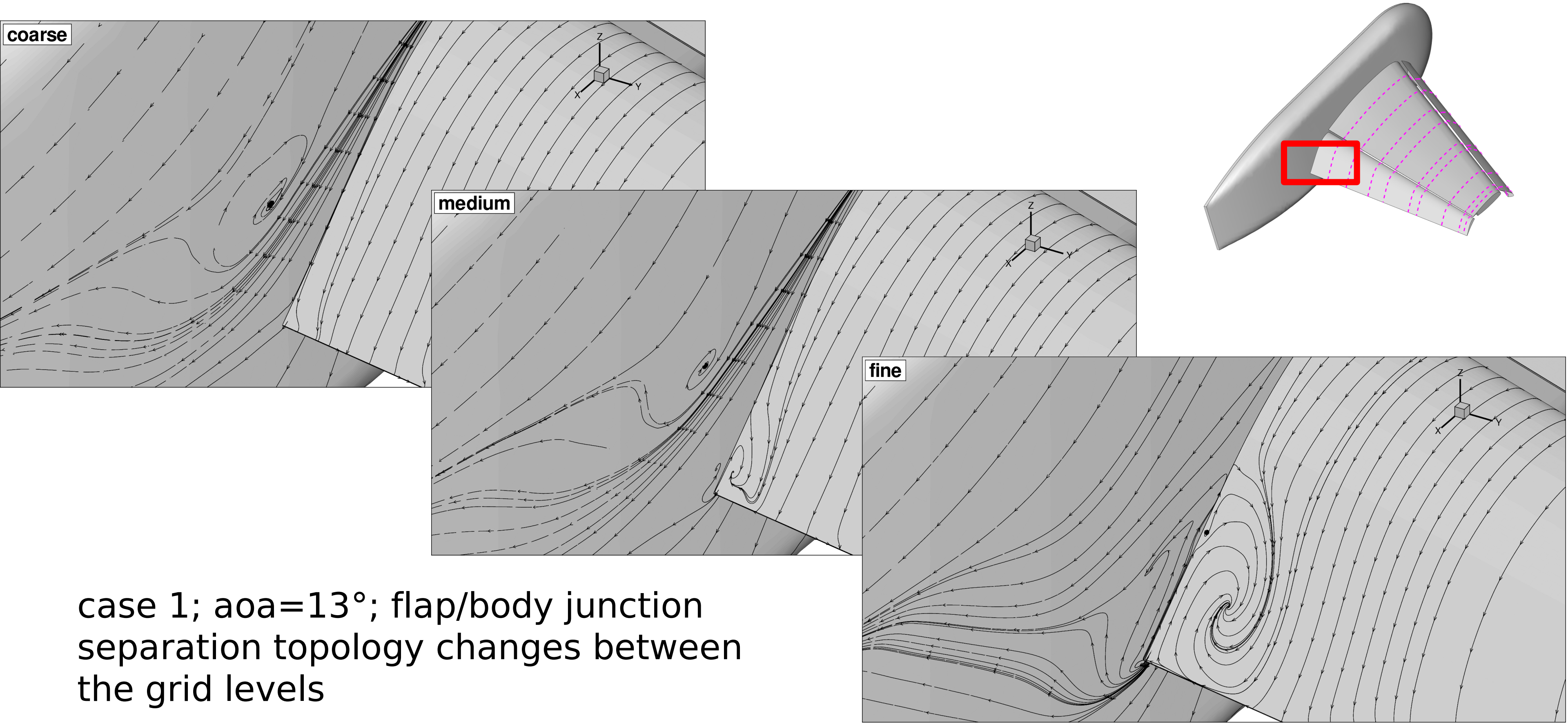
- For aoa=28°, no grid convergence in tip region either



case 1; aoa=28°; pressure coefficient on main element (left) and flap (right) at y/2b=98%

Grid Convergence

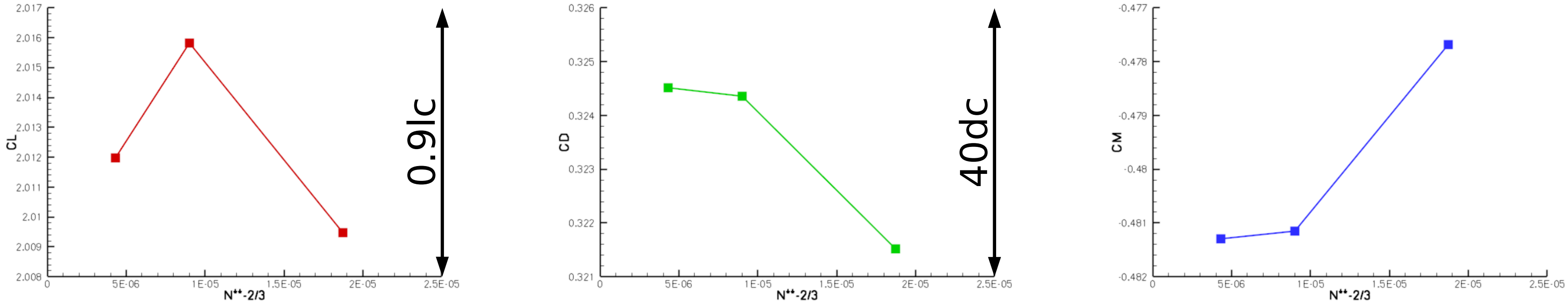
- Grid independence not achieved in terms of flap/body separation, over entire aoa range



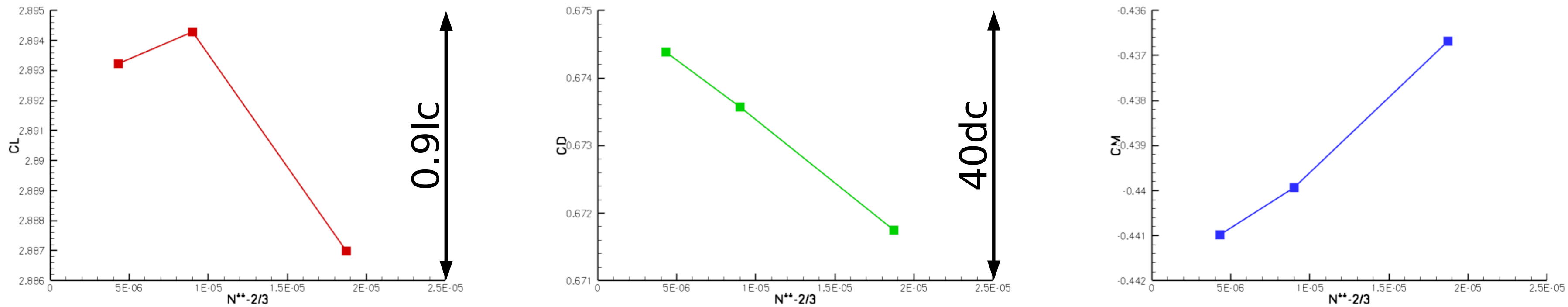
case 1; aoa=13°; flap/body junction separation topology changes between the grid levels

Grid Convergence

- Grid convergence for integrated quantities satisfactory



aoa=13°

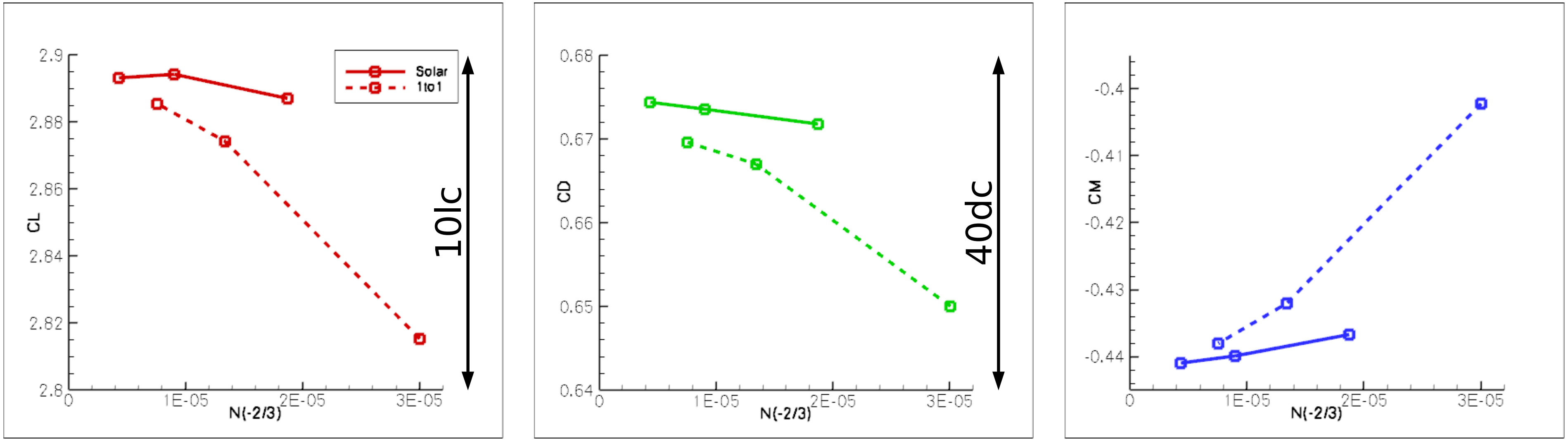


aoa=28°

Integrated quantities plotted over the grid scaling factor, $N^{-2/3}$; note different relative scales in lift and drag plots

Grid Convergence

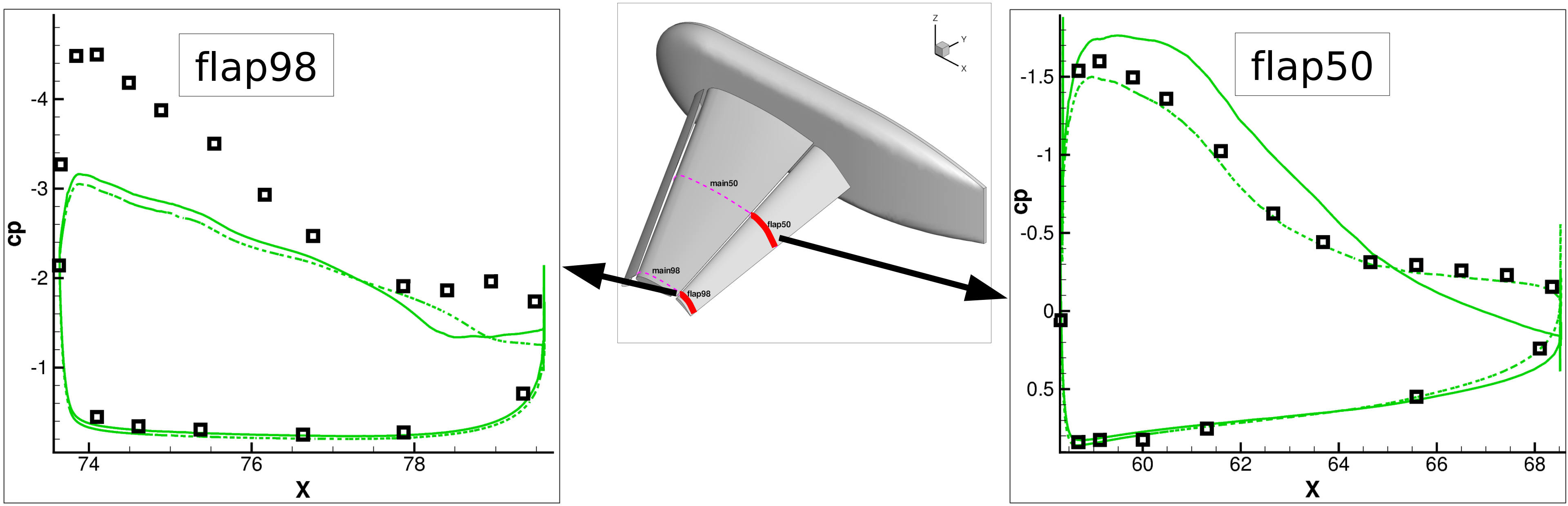
- Comparison of grid convergence for integrated quantities between Solar and 1to1 (Unst-Hex-FromOnetoOne-A-v1; ICEMCFD/Boeing) grid family



aoa=28°

Brackets Effect

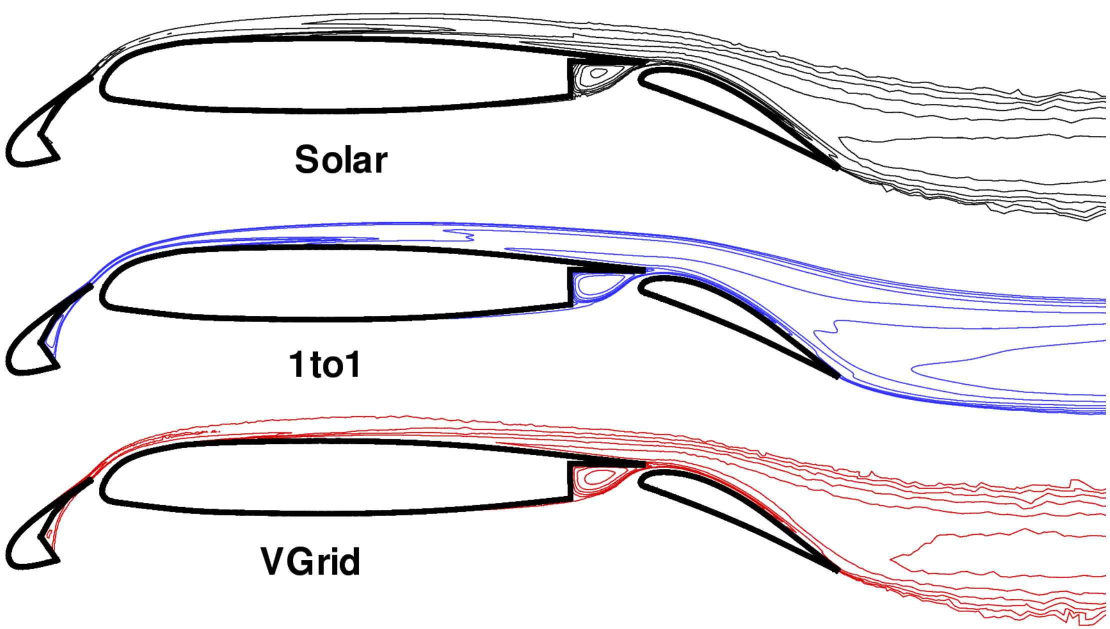
- At 28°, pressure data on mid-span flap from case 3 (with brackets) fits better the experimental data than case 1, although the match in terms of integrated values (C-lift and C-drag) is worse
- This is possibly due to better match (less lift on flap for case 3) at mid-span, but equally bad tip region resolution, net result is less total lift

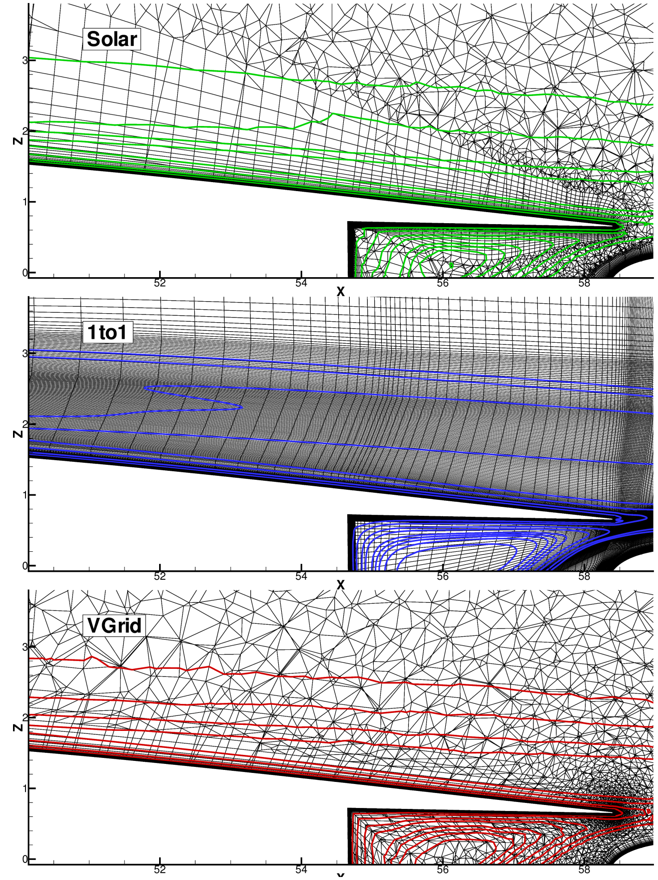


Case 1 (green, continuous) compared to case 3 (green, dashed) and experimental data (square, black symbols); aoa=28°; y/2b=98% and 50%

Wake Resolution

- Wake resolution issues remain with standard advancing-layer techniques





main50

Conclusions & Outlook

- Grid generation process
  - Gained experience with peculiarities of Solar grid generation for high-lift configurations
  - Near-field (junctions) and wake resolution issues remain to be resolved; HiLiftPW/Trap-Wing good candidate for evaluation of solution strategies
- Satisfactory grid convergence achieved with TAU
  - Tip vortex issue remains
  - Similarities to DPW4 studies identified, need to harvest on synergy effect